LINE-HEAT-SOURCE GUARDED-HOT-PLATE APPARATUS

Complying with the Requirements of

ASTM TEST METHOD FOR STEADY-STATE THERMAL TRANSMISSION PROPERTIES BY MEANS OF THE GUARDED-HOT-PLATE APPARATUS C 177

and

ASTM PRACTICE FOR GUARDED-HOT-PLATE DESIGN USING CIRCULAR LINE-HEAT-SOURCES C 1043

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Abstract: This adjunct describes the line-heat-source guarded-hot-plate apparatus fabricated by the National Institute of Standards and Technology. It is intended as a guide in the design and construction of a guarded hot plate having circular line heat sources. The essential requirements for steady-state testing of heat insulators are described in ASTM Test Method C 177 and the essential requirements for the design of guarded hot plates having circular line-heat-sources are covered in ASTM Practice C 1043.

Introduction

In contrast to a (conventional) guarded hot plate that uses uniformly distributed heaters, a line-heat-source guarded hot plate utilizes circular line-heat sources in the meter and guard plates at precisely specified locations. The application of circular line-heat sources generally presupposes plates having a circular geometry. By proper location of the line-heat-source(s), the temperature at the edge of the meter plate can be made equal to the mean temperature of the meter plate, thereby facilitating temperature measurements and thermal guarding. For a single line-heat source in the meter plate, the mean surface temperature is closely approximated by the temperature at the edge, provided that the line-heat source is located at a radius of $a = r/\sqrt{2}$ from the center, where r is the radius of the meter plate. The benefits offered by a line-heat-source guarded hot plate include: simpler methods of construction; improved accuracy; simplified mathematical analyses for calculating the mean surface temperature of the plate as well as determining the errors resulting from heat gains or losses at the edges of the specimens; and, use under vacuum conditions.

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Over the course of sixteen years, the National Institute of Standards and Technology (NIST) proposed, designed, and built two line-heat-source guarded hot plates. These apparatus, typically identified by the outer diameter of the plates, are known as the 305-mm and 1016-mm line-heat-source guarded hot plate apparatus. Eventually, these apparatus replaced the final version of the 203-mm square, distributed heat-source guarded hot plate (1) that was constructed at the U.S. National Bureau of Standards (now known as NIST) about 1929 (see ASTM C 177 Adjunct). This paper describes the history of the line-heat-source technology used in the guarded hot plate, an overview of the apparatus fabricated at NIST, detailed design drawings of the apparatus, and some comments on temperature sensors and control. An Appendix provides instructions for assembly of the plates.

History

In 1964, Robinson of NIST first presented the basic design of the line-heat-source guarded hot plate to a thermal conductivity conference sponsored by the National Physical Laboratory in England. The design was reported in *Nature* (2) as follows:

> H.E. Robinson (U.S. National Bureau of Standards) discussed forms of line heat sources that could be used as heaters in apparatus for measurements at lower temperatures on insulating materials in disk and slab form. These new configurations lend themselves more readily to mathematical analysis, they are more simple to use and would appear to be able to yield more accurate results.

In 1971, Hahn (3) conducted an in-depth analysis of the line-heat-source concept and investigated several design options. Subsequently, in 1973, the design, mathematical analysis, and uncertainty analysis for a line-heat-source guarded hot plate were published at an ASTM Symposium by Hahn, Robinson, and Flynn (4). NIST began construction of the prototype apparatus in 1975 and completed the apparatus in 1978. The development of the design and construction of the prototype apparatus was presented by Powell and Siu (5). The performance and uncertainty analysis was published in 1981 by Siu and Bulik (6).

Because of the promising results from the prototype, NIST began plans for a second, larger line-heat-source guarded hot plate apparatus. The construction of the second-generation apparatus was greatly accelerated due to a ruling by the U.S. Federal Trade Commission (7) in 1980 concerning the labeling and advertising of home insulation. The second-generation apparatus was completed near the end of 1980 under the supervision of Hahn. Measurement services for the public began early in 1981. The development of the design and construction of the apparatus was presented in 1982 by Powell and Rennex (8). An error analysis of the apparatus was published in 1983 by Rennex (9).

Overview

An overview of the physical specifications and operating requirements of the line-heat-source apparatus constructed by NIST is provided in Tables 1 and 2. The tables provide a quick side-by-side comparison of the two apparatus. Note that although the 1016 mm (2nd generation) apparatus was designed to test larger and thicker specimens, the temperature range is somewhat reduced. At present, the 305 mm guarded hot plate apparatus is no longer in service. The 1016 mm guarded hot plate provides thick reference materials, particularly low-density fibrous-glass insulation specimens, for the public.

Table 1 - Physical Specifications of the NIST Line-Heat-Source Guarded Hot Plate Apparatus

Physical Parameter	Prototype	2nd-Generation
Plate material	copper (99.99 percent)	aluminum (6061-T6)
Plate coating	flat black paint	anodized black
Normal emittance	0.90	0.89
Guard plate diameter, mm	304.8	1016.0
Meter plate diameter, mm	151.6	405.6
Number of heaters in meter plate	1	1
Radius of line-heat source in meter plate, mm	107.2	287.0
Type of line-heat source in meter plate	ribbon heater	ribbon heater
Electrical resistance of meter plate heater, Ω	17	58
Type of temperature sensors	thermocouple, type T	platinum resistance

Table 2 - Operating Requirements of the NIST Line-Heat-Source Guarded Hot Plate Apparatus

Physical Parameter	Prototype	2nd-Generation
Plate orientation	vertical or horizontal	vertical or horizontal
Maximum specimen thickness, mm	50.8	304.8
Maximum hot plate temperature, °C	250	150
Range of cold plate temperatures, °C	−40 to 100	−40 to 100
Specimen conductance, $W/(m^2 \cdot K)$	60	7
Required measurement precision, percent	1	1
Construction completed, year	1978	1980

305-mm Line-Heat-Source Guarded Hot Plate[2] (Prototype)

Assembled Apparatus

The assembled 305-mm line-heat-source guarded hot plate apparatus is shown in Figure 1 (cut-away view) and Figure 2 (assembly drawing). Two similar specimens are placed on either side of the guarded hot plate between the circular cold plates. All of the plates are machined from 99.99 percent pure copper. The metal surfaces in contact with the specimens are finished to a flatness of 0.03 mm and coated with a flat black paint to provide a total normal emittance of 0.90 $\pm$ 0.05. The plates are supported by wires attached to steel rings that slide on bearing rods of a circular support cage. The specimens are clamped in place by pressure cups on either side of the cold plates. The clamping pressure is transmitted by means of a weight suspended on the L-shaped bracket, Figure 2. The support cage is enclosed by an insulated chamber whose temperature and pressure can be controlled. With proper modifications, the apparatus can be used in a horizontal or vertical position.

Guarded Hot Plate

The guarded hot plate is made from free-machining copper (99.99 percent) having an outer diameter of 304.8 mm and a thickness of 11.1 mm (9.5 mm minimum), Figure 3[3]. The dimensions of the plate were selected based on the results of the analyses described in References (3) and (4). Copper was selected because of its high thermal conductivity, low cost, reasonably low volumetric heat capacity, a wide usable temperature range, good oxidation resistance when coated with a (required) high emittance paint, good dimensional stability, insignificant warpage over its intended temperature range, and ease of machining, fabrication, assembly and repair.

The guarded hot plate consists of a meter plate having a diameter of 151.6 mm and a co-planar, concentric guard plate with an inner diameter of 153.2 mm, Figure 3. The separation between plates, known as the gap, is 0.81 mm at the flat surfaces of the plates. The profile of the gap is diamond-shaped to minimize lateral heat flows across the gap and facilitate assembly. The meter plate is supported by three 304-stainless steel pins that are pushed radially across the gap. The pins have tapered ends that press into the adjoining edge of the meter plate. Three tapered-end set-screws in the guard plate are used to adjust the gap to a uniform width and maintain the meter plate in plane with the guard plate, Figure 3.

The circular line-heat-source for the meter plate is located at a diameter of 107.2 mm as illustrated in Figure 3. Originally (3), a swaged-type heating element was specified. However, the design was subsequently changed in 1975 to a ribbon-type heating element as shown in Figure 4. The ribbon heater is a thin nichrome filament network, 0.08 mm thick and 9.3 mm wide, electrically insulated with polyamide and having an electrical resistance at room temperature of 17 Ω. The design for a ribbon heater requires a tapered fit for the meter plate as shown in Figure 4. The current lead wires for the ribbon heater are brought out radially through small holes to the periphery of the guard plate.

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[2] This apparatus is also known as the Robinson line-heat-source guarded hot plate apparatus in recognition of Henry E. Robinson of NIST.

[3] As noted in the drawings, this apparatus, and the 1016-mm apparatus, were designed using the English system of units. However, in accordance with NIST policy, the text describes the apparatus using SI units.

The circular line-heat-source used in the guard plate is located at a diameter of 197.8 mm. The design, shown in Figures 3 and 4, specifies a swaged-type heating element. The element is 1.59 mm in diameter and made from 0.16 mm diameter nichrome wire surrounded by magnesium-oxide electrical insulation and a protective sheath of 304 stainless steel. The electrical resistance of the nichrome wire at room temperature is 66 Ω. The swaged-heater is silver-soldered into a groove 7.14 mm deep in the guard plate. The current leads are brought out through radial grooves in the guard plate to the periphery of guard plate.

The guarded hot plate was designed to be cooled quickly, if desired, by circulating cold gas through the gap of the meter plate. For this purpose, two holes, 1.6 mm in diameter, are drilled radially in the guard plate to the gap, Figure 3. The holes are drilled at an angle to avoid crossing the guard heater wires.

Power Measurements

A 50-V direct current power supply provides electrical current to the ribbon heater (17 Ω) in the meter plate. The power supplied to the meter plate is determined by measuring the voltage drop across the heater and the corresponding current. The voltage drop across the heater is measured directly at voltage taps in the center of the gap. The current is determined from the voltage drop across a standard resistor, 0.01 Ω, in series with the heater.

Temperature Sensors in the Gap

The average temperature of the meter plate and the temperature difference across the gap are measured using type-T, copper-constantan thermocouples that are checked by a platinum resistance thermometer located in one of the cold plates. The wiring design of the temperature sensors allows the measurement of either individual temperatures or a differential temperature across the gap, Figure 5. All thermocouples were calibrated initially by the Temperature and Pressure Measurement Division of NIST to an uncertainty of $\pm$ 0.1 K. The thermocouple voltages are referenced to the ice point of distilled water and measured by means of a potentiometer with a resolution of $\pm$ 0.1 μV ($\pm$ 0.002 K). The thermocouple junctions are also calibrated in place against the platinum resistance thermometer by clamping the cold plates and the hot plate together directly without specimens.

The temperature sensors for the meter plate are located at the periphery of the meter plate at azimuthal angles of 69, 180, and 291 degrees relative to the position of the meter plate heater leads, Figure 6. These locations are chosen to yield the temperature at the edge of the meter plate that most closely approximates the average temperature of the entire meter plate (3,4). Temperature sensors are also installed around the inner edge of the guard plate at 31, 133, 227, and 329 angular degrees (3,4), Figure 6. The thermocouple beads are mechanically attached to the V-grooves of the meter plate and guard plate as shown in Figure 7. The brass tubes (3 mm long by 0.7 mm outer diameter) for housing thermocouples are silver soldered at the apex of the inner and outer grooves at the angular locations specified above.

Temperature Sensors at the Plate Edge

Angular locations for the average temperature at the edge of the guarded hot plate are shown in Figure 6. The surface thermocouples and ambient temperature are used to determine the convection coefficient at the edge.

Cold Plates

An assembly view of a single cold plate is shown in Figure 8. The plate consists of a disc of free-machining copper (99.99 percent), 304.8 mm in diameter and 19.1 mm thick that has a double spiral groove, 12.7 mm wide and 9.5 mm deep, cut into one face. The grooved disk is covered by a 6.4 mm thick plate also of 99.99 percent pure copper that is silver-soldered in place. The double spiral groove allows fluid to flow in parallel counter flow paths through the cold plate. The temperature of the cold plate is maintained by circulating liquid coolant (a 40 percent ethylene-glycol, water solution) from a refrigerated bath which regulates the cold bath within $\pm$ 0.05 K over a temperature range of -40 to 100 °C.

The temperature of the cold plate is measured by a calibrated type-T thermocouple. A small calibrated platinum resistance thermometer provides a known reference temperature for all thermocouple sensors. The sensors are placed in one of the 1.59 mm diameter holes drilled radially to a depth of 114.3 mm at a location 4.8 mm from the surface in contact with the specimens. A control thermistor in one cold plate is used to maintain the cold plate temperatures by providing a feedback signal for a refrigerated bath. Temperature differences between the hot and cold plates are measured directly with a type-T thermocouple in the meter plate connected differentially to each cold plate.

Environmental Chamber

Detail drawings for the components of the circular support cage (type 304 stainless steel) are shown in Figures 9 through 12. The entire assembly is placed on a flat table under an insulated hood that can be raised and lowered. The temperature of the ambient air in the enclosure is maintained by means of a conventional refrigeration system, electrical resistance heaters, and a circulation fan. The air within the chamber can be maintained within $\pm$ 1 K.

Specimen Thickness

The thickness of the specimens is measured during testing using three high-temperature linear variable differential transformers (LVDTs) that are mounted at the periphery of one cold plate with brackets of Invar (alloy of Fe, Ni, C, and Cr) and with the cores supported from the other cold plate. The transducers are calibrated using rigid spacers of known thickness placed between the cold and hot plates.

1016-mm Line-Heat-Source Guarded Hot Plate (2nd Generation)

Assembled Apparatus

The assembled 1016-mm line-heat-source guarded hot plate apparatus is shown in Figure 13. Two similar specimens are placed on either side of the guarded hot plate between the circular cold plates. The plates are made from an aluminum alloy, type 6061-T6. The finished surfaces in contact with the specimens are flat to within 0.05 mm and are anodized black to have a total normal emittance of 0.89. The hot plate is rigidly mounted on four bearing rods. Each cold plate is supported at its geometric center by means of a swivel ball joint that allows the plate to tilt and conform to a nonparallel rigid sample. The clamping force is transmitted axially by extension rods that are driven by a stepper motor and a worm-drive gear. A load cell measures the axial force that the plate exerts on the specimen. The cold plates are constrained in the radial direction by steel cables attached to four spring-loaded bearings that slide on the bearing rods. The plates are enclosed by an insulated environmental chamber that can be rotated ± 180 angular degrees.

Guarded Hot Plate

The guarded hot plate is made from aluminum alloy type 6061-T6 and is 1016 mm in diameter and nominally 16.1 mm thick, Figure 14. The design for the 1016-mm guarded hot plate, like the prototype, is based on the information described in References (3) and (4) and also an unpublished analysis by Hahn. Several metals were considered, among them copper, aluminum, and gold. Aluminum was selected primarily because of its relatively light weight and low cost, as well as its high thermal conductivity, reasonably low volumetric heat capacity, a wide usable temperature range, good oxidation resistance when anodized, good dimensional stability, insignificant warpage over its intended temperature range, and ease of machining, fabrication, assembly and repair. The nominal plate thickness of 16.1 mm was selected to provide adequate structural rigidity while minimizing the volumetric heat capacity.

The 1016 mm guarded hot plate consists of a meter plate[4] 405.6 mm in diameter and a co-planar, concentric guard plate with an inner diameter of 407.2 mm, Figures 14 and 15. The separation between the plates is 0.8 mm at the flat surfaces of the plates. The profile of the gap is also diamond shaped in order to minimize lateral heat flows across the gap and facilitate assembly. The meter plate is supported by three stainless steel pins, equally spaced, that are pushed radially across the gap. The pins have tapered ends that press into the adjoining edge of the meter plate. Three tapered-end set-screws in the guard plate are used to adjust the gap to a uniform width and maintain the meter plate in plane with the guard plate. The flatness across the diameter of the meter plate is less than 0.025 mm.

The circular line-heat-source for the meter plate is located at a diameter of 287.0 mm and is a ribbon-type heating element, Figure 15. The element is a thin nichrome filament network, 0.1 mm thick and 4 mm wide, electrically insulated with polyamide having an electrical resistance at room temperature of approximately 58 Ω. The assembly of the meter plate and ribbon heater requires a thermal expansion fit as described in Appendix A. The current lead wires for the ribbon heater are brought out radially through small holes to the periphery of the guard plate.

Unlike the 305-mm apparatus, there are two circular line-heat-sources in the guard plate located at diameters of 524.7 mm and 802.2 mm, Figure 14. The heaters are swaged-type heating elements, 1.59 mm in diameter, similar to the type used in the 305-mm plate. The electrical resistances at room temperature for the inner and outer guard heaters are approximately 72 and 108 Ω, respectively. The heaters are placed in circular grooves cut in the surfaces of the guard plate. The grooves are subsequently filled with a high temperature epoxy as described in Appendix A. The current leads are brought out through radial holes in the guard plate to the periphery of guard plate.

The guarded hot plate was designed to be cooled quickly, if desired, by circulating cold gas through the gap of the meter plate. For this purpose, two holes, 3.3 mm in diameter, are drilled radially in the guard plate to the gap, Figures 14 and 15. Because the circular line heat sources in the guard plate are placed near the surface, the holes are drilled at the midplane of the plate, Figure 14.

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[4] Terminology for the 1016 mm guarded hot plate reflects current usage in ASTM Practice C 1043.

Power Measurements

A 40-V direct current power supply provides electrical current to the ribbon heater (58 Ω) in the meter plate. The power supplied to the meter plate is determined by measuring the voltage drop across the heater and the corresponding current. The voltage across the heater is measured directly at voltage taps in the center of the gap. The current is determined from the voltage drop across a standard resistor, 0.1 Ω, in series with the heater.

Temperature Sensors in the Gap

The average temperature of the meter plate is measured with a small, calibrated platinum resistance thermometer (PRT) having an outer diameter of 3.2 mm. The PRT is composed of an element of chemically pure, strain-free platinum wire wound in a hermetically sealed, dry, helium environment. The nominal resistance at 0 °C is 100 Ω. The PRT was calibrated by the Thermometry Group at NIST to an (expanded, $k=2$) uncertainty of 0.01 K over a range of −40 to 120 °C. (All temperatures are reported in the International Temperature Scale of 1990, ITS-90). The resistance of the PRT is measured with a 4-wire electrical resistance measurement using a 5½ digit, integrating voltmeter. The PRT is located at the periphery of the meter plate at the angular position of 291 degrees relative to the entry of the meter heater leads across the gap, Figure 15. The PRT is mechanically fastened to the meter plate using a small bracket as illustrated in Figure 15 (item 4, drawing 939001).

The temperature difference across the gap is measured using type-E (nickel-chromium, constantan), 30 AWG, teflon-insulated thermocouples connected differentially in a 4-junction thermopile. The thermocouple junctions are welded beads from selected lengths of type EP (nickel-chromium) and EN (constantan) wire. The wire lengths were taken from spools of wire that were scanned using a large temperature gradient (i.e., a bath of liquid nitrogen) to isolate inhomogeneities in the wire. The junctions for the meter plate are located at the periphery of the meter plate at azimuthal angles of 69, 120, 240, and 291 degrees relative to the position of the meter heater leads, Figure 15. These locations are chosen to yield the temperature at the edge of the meter plate that most closely approximates the average temperature of the entire meter plate (3). The junctions for the guard are installed around the inner edge of the guard plate at 45, 135, 225, and 315 angular degrees, Figure 14. The thermocouple beads are mechanically attached to the V-grooves of the plates using the small brackets detailed in Figure 15 (item 3, drawing 939001).

In addition to the primary sensors described above, several secondary temperature sensors were assembled and installed in the gap as a precautionary check. The absolute temperatures at the locations of the differential thermopile were measured using individual type-E, 36 AWG thermocouples. The thermocouples were calibrated collectively in a tube of oil placed in a precision-controlled refrigerated bath. One of the thermocouples was subsequently calibrated by the Thermometry Group at NIST to within 0.2 K. A pair of thermistors, one for the meter plate and the other for the guard plate, are installed in the gap at angular positions of 240 degrees (meter side) and 225 degrees (guard side).

Cold Plates

The cold plates are fabricated from 6061-T6 aluminum and designed to circulate a solution of ethylene glycol and distilled water. The assembly and construction details of a single cold plate are shown in Figures 16-18. Each aluminum plate is 25.4 mm thick and consists of a 6.4-mm-thick cover plate bonded with epoxy to a 19.1-mm-thick base plate. The base plate contains milled grooves 9.5 mm deep and 19.1 mm wide arranged in a double-spiral configuration. This arrangement provides leak-tight counterflow channels, allowing the incoming coolant to pass next to the outgoing coolant for a more uniform temperature distribution over the cold-plate surface. The temperature of the cold plate is maintained by circulating liquid coolant from a refrigerated bath which regulates the cold bath within ± 0.05 K over a temperature range of −20 to 60 °C. The outer surfaces and edges of the cold plates are insulated with 102 mm of extruded polystyrene.

The temperature of the cold plate is determined using a calibrated platinum resistance thermometer (PRT). A 3.3-mm diameter hole, 457 mm deep, was bored through the side of the plate to provide access for installing a platinum resistance thermometer. To check the radial temperature profile, six type-E thermocouples are epoxied at different radii in a single groove cut in the cover plate (not shown).

Environmental Chamber

The environmental chamber is a large rectangular chamber having inside dimensions approximately 1.40 m square by 1.60 m high. The chamber walls are composed of 75-mm-thick rigid polyurethane foam insulation sandwiched between 1.4-mm-thick sheets of reinforced fiberglass plastic. The inside and outside surfaces of the chamber are finished with thin sheets of aluminum. The bearing rods for supporting the plates are secured externally at only the top of the chamber. Rigidity for the chamber is provided by an exterior frame of 50-mm aluminum square tubes. The chamber is centrally supported by axles that are mounted on gimbals, allowing 180 degrees of rotation for the entire apparatus. Access to the plates is allowed by double-doors located on both the front and back of the chamber. The temperature within the chamber is maintained within ± 0.5 K using five type-T thermocouples that average the air temperature of the chamber. The temperature range of the chamber is 0 to 60 °C.

Specimen Thickness

The thickness of each specimen is measured during testing using the average of four, equally spaced, linear positioning devices located at the periphery of the plates. The linear positioning transducer consists of a 450-mm Invar scale and slider, and digital indicator. The scale is attached to the center point of the guarded hot plate support rod, parallel to the direction of movement of the cold plates. The slider translates linearly on the scale by means of three roller bearings and is connected rigidly to the cold plate. The position of the slider controls the magnitude of the output signal which is resolved and processed by the digital indicator. Thus, the output signal represents the distance between the translating cold plate and the fixed guarded hot plate. The digital indicator is set by either placing the cold plates adjacent to the guarded hot plate or by placing a set of four fused-quartz spacers of known thickness between the plates. The thickness of the specimen is taken as the average of the readings of the four sliders and provides the in-situ thickness under actual test conditions.

Temperature Control

A few comments are included here concerning the temperature control of the 1016 mm guarded hot plate. The three heaters in the guarded hot plate are controlled by a digital proportional, integral (PI) control algorithm. The basis for this computer algorithm is taken from Raven (10) and is developed below.

A classical control algorithm using proportional and integral control for a continuous process in time, t, is provided in Equation (1):

$$m(t) = (K_1 + K_2 D^{-1}) e(t) \tag{1}$$

where; $m(t)$ is the real-time output of the process, $e(t)$ is the real-time error between the process variable and the reference set point (i.e., target); and K_1 and K_2 are the proportional and integral constants adjusted by the user, respectively. The symbol D^{-1} indicates integration with respect to time. Sequential sampling of data at a periodic interval, T, requires a "discrete equivalent" of the classical control algorithm. Approximating the integral using rectangular integration yields:

$$m(k) = K_1 e(k) + K_2 T \sum_{n=1}^{k} e(n) + m(0) \tag{2}$$

where; $m(k)$ and $e(k)$ are the process output and error, respectively at sample interval k. Modifying Equation (2) by replacing k by $k-1$ and subtracting yields:

$$\Delta m(k) = m(k) - m(k-1) = K_1[e(k) - e(k-1)] + K_2 T e(k) \tag{3}$$

The primary advantage of Equation (3) is the elimination of the summation term reducing the effect of accumulated errors. Accumulated errors in Equation (2) can cause large overshoots. Our experience at NIST has shown that control algorithms based on Equation (3) provide superior results in obtaining steady-state conditions for the guarded hot plate.

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APPENDIX A - ASSEMBLY OF THE 1016-mm COLD PLATE AND GUARDED HOT PLATE

Procedure for Assembly of Cold Plate (Refer to Drawing #939005 - Figure 18)

1. Clean base and cover plates with alcohol or other organic solvent to remove grease.

2. Temporarily assemble the drain plug. Apply a mold-release agent on the rod to prevent clogging due to excess epoxy.

3. Place the base plate on a flat table, grooved-side up.

4. Mix a two-part epoxy according to the manufacturer's recommended procedures. De-aerate bubbles trapped in the mixed epoxy by placing the epoxy mixture in a vacuum chamber for about 5 minutes.

5. Apply epoxy on the (top) surfaces of double spiral grooves, center boss, and outer perimeter. Spread epoxy to a uniform thickness and remove excess epoxy from the grooves. Avoid placing epoxy into any threaded holes. Apply epoxy within recommended working time.

6. Align the cover plate in-line with the liquid inlet and outlet holes using the locating pins.

7. Lower the cover plate uniformly and assemble with bolts (¼-20 by 0.75L, and ½-20 by 0.75L, hex head bolt). The center bolt (½-20 by 0.75) can be removed after epoxy has cured. Replace with permanent fixture after epoxy has set.

8. Turn the assembled plate over to prevent excess epoxy from running down into the grooves. Place the assembled plate in an oven, cover plate down. Cure the epoxy, following the manufacture's recommended curing temperature, time, and cool-down procedure.

Installation of Ribbon Heater in the Meter Plate (Refer to Drawing #939001 - Figure 15)

1. The inner meter disk and outer meter ring are assembled with a heater placed between them by means of a thermal expansion fit. The individual components - the meter disk, meter ring, ribbon heater, and lead wires - are shown in Figure A1.

2. Determine, by calculation or experiment, the temperature necessary for the inner disk to fit in the outer ring by heating the outer ring above the room temperature. If necessary, a series of measurements in an oven can be carried out to obtain the necessary temperature for expansion of the outer ring. A minimum of 0.2 mm (0.008 in.) clearance between the outer diameter of the inner disk and the inner diameter of the outer ring is recommended.

3. Insert the lead wires of the ribbon heater and voltage taps through the lead wire hole in the outer ring. Press the foil heater into the heater grooves of the outer ring. Use an adhesive or epoxy cement on the ribbon heater to hold the heater in the groove during assembly. If desired, coat the other side of the ribbon heater with a thermally conductive paste for good thermal contact. Make sure the adhesive, epoxy, and paste have suitable temperature limits compatible with the desired operating limits of the apparatus.

4. Place the outer ring in an oven and gradually increase the temperature of the oven to the temperature determined in step 2. Quickly check the inner diameter by measuring with calipers. If necessary, cool the inner disk to a temperature below ambient but above the dew point temperature.

5. Remove the outer ring from the oven. Place on flat-plate glass that is thermally insulated underneath to prevent rapid cooling of the outer ring.

6. Carefully and quickly insert the inner disk in the center of the outer ring and align with the heater groove. The outer ring will gradually shrink and hold the inner disk.

<u>Installation of Swaged Heater in Guard Plate (Refer to Drawing #939002 - Figure 14)</u>

1. Two circular line heaters are designed for the guard plate. Each circular groove in the guard plate contains a single swaged heater that is inserted from one side of guard plate and passes through a slotted section to form a symmetric circular line heat source.

2. Cut the length of each swaged heater slightly longer than the total length of each groove.

3. Insert the swaged heater through the slotted section of the groove, as shown in cross-section C-C of drawing #939002, by one half length of swaged heater.

4. Press the swaged heater into the groove with a suitable tool. To achieve good thermal contact between the swaged heater and groove, minimize bending and stretching of the heater. Trim the excess length of the heater at the lead wire junction as shown in cross-section C-C, drawing #939002. Remove the swaged cover from the same end in preparation for electrical connection.

5. Repeat the same procedure for opposite side of the guard plate.

6. Connect the lead wires to the heater element at the point where the swaged heater diagonally crosses the plate.

7. Electrically insulate the exposed heater wire between the end of the metal sheath and lead wires with a high-temperature electrical insulation material.

8. Install all swaged heaters in the same manner as above.

9. After installation of heaters, prepare a two-part epoxy for final finish. Fill the groove with epoxy, covering the swaged heater. Use a suitable nozzle dispenser for applying epoxy to fill all grooves completely. Avoid trapping air bubbles in the epoxy.

10. Cure the epoxy according to the manufacturer's recommended procedures (i.e., temperature, time, and cool-down).

Procedure for Assembly of the Hot Plate (Refer to Drawing #939002 - Figure 14)

1. Assemble the meter plate and guard plate with 3 support pins.

2. After assembly, grind both circular surfaces of the plate to their final specifications of thickness, flatness, and parallelism. Note that the initial thicknesses of the meter plate and guard plate should be machined slightly thicker than the final thickness to allow for final grinding.

3. In preparation for anodizing the aluminum plate, remove the 3 support pins and separate the meter plate and guard plate. Clean all metal surfaces. Seal all openings, particularly entrances for lead wires, where the anodizing fluid may possibly penetrate and damage the heaters.

4. Black anodize the meter plate and guard plate to obtain the specified emittance.

5. Install the temperature sensors, voltage tap wires, and other sensors in the meter plate and guard plate.

6. Reassemble the meter plate and guard plate with the 3 support pins.

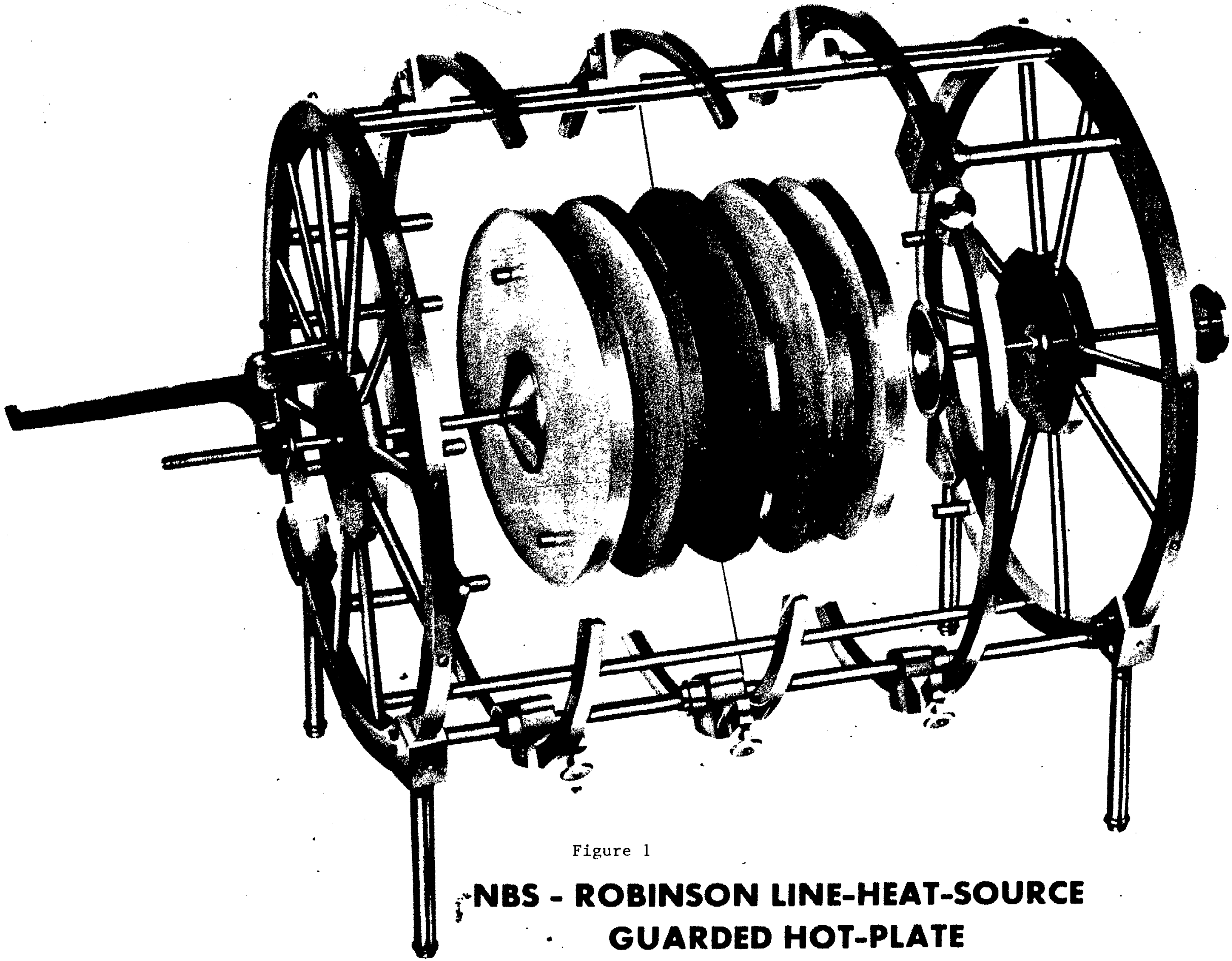


Figure 1

NBS - ROBINSON LINE-HEAT-SOURCE GUARDED HOT-PLATE

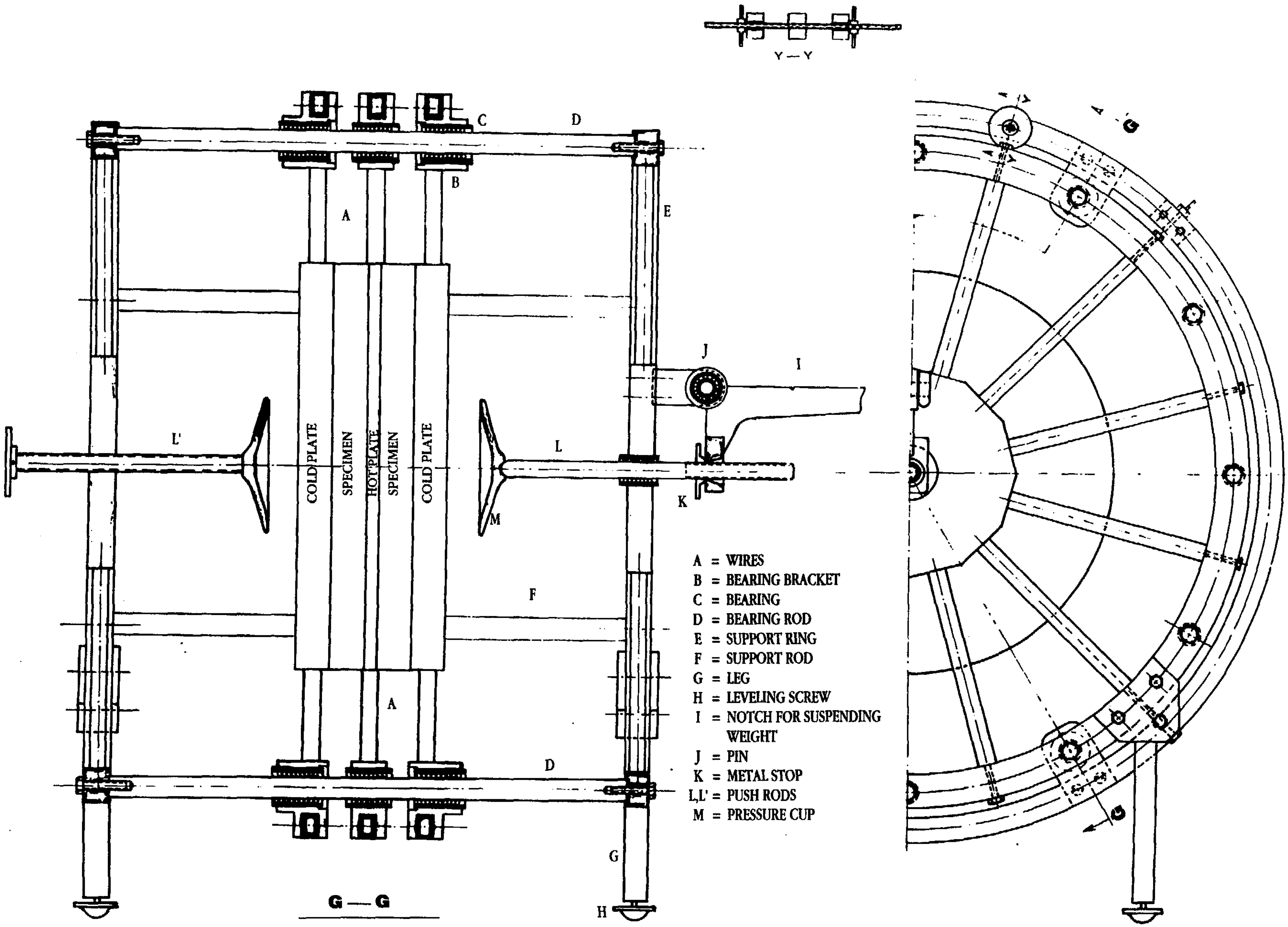
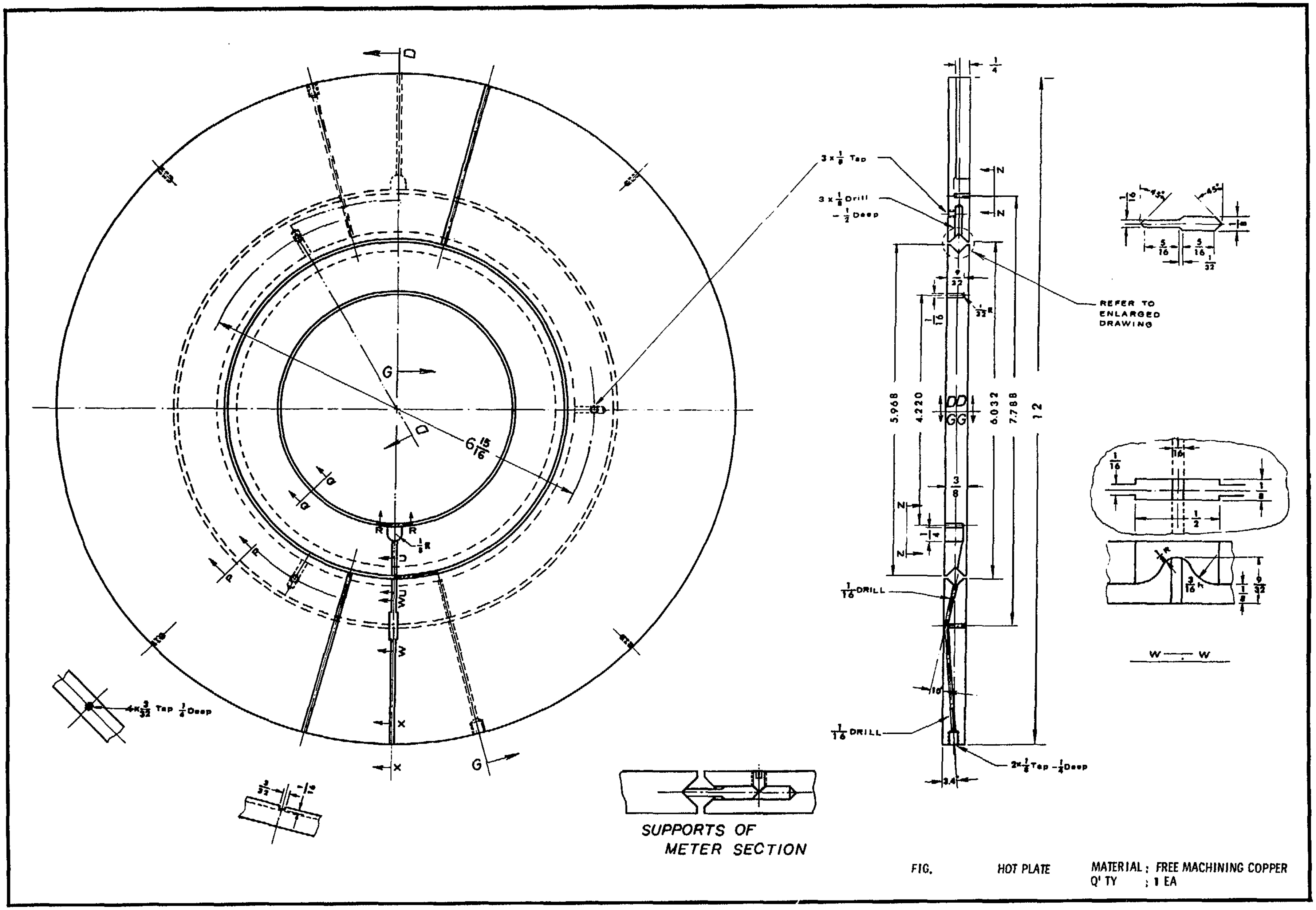


Fig. ASSEMBLY OF APPARATUS

Figure 2



3 x 1/8 Tap
3 x 1/8 Drill - 1/2 Deep
REFER TO ENLARGED DRAWING
5.968
4.220
6.032
7.788
12
1/16 DRILL
2x 1/8 Tap - 1/4 Deep
4x 3/32 Tap 1/4 Deep
W — W
SUPPORTS OF METER SECTION
FIG.
HOT PLATE
MATERIAL ; FREE MACHINING COPPER
Q' TY ; 1 EA

Figure 3

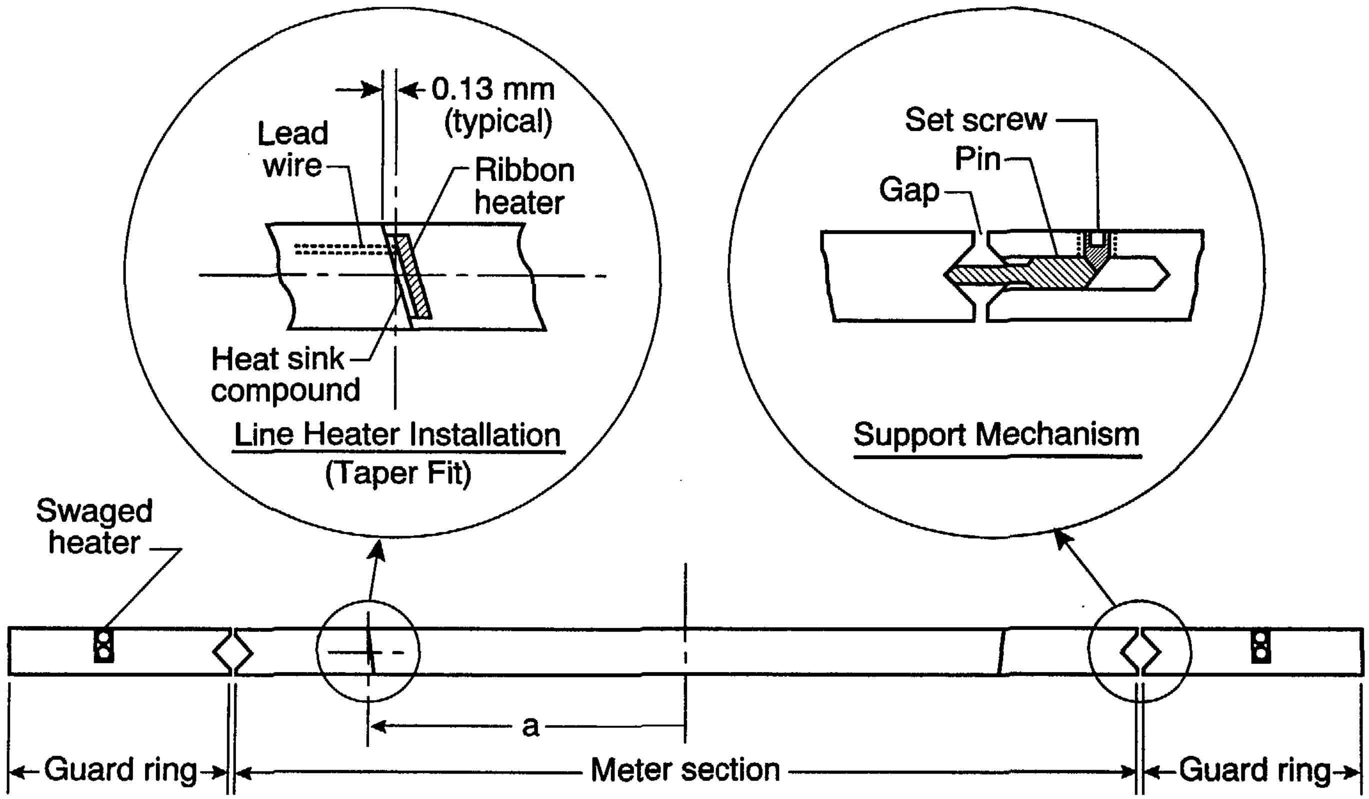
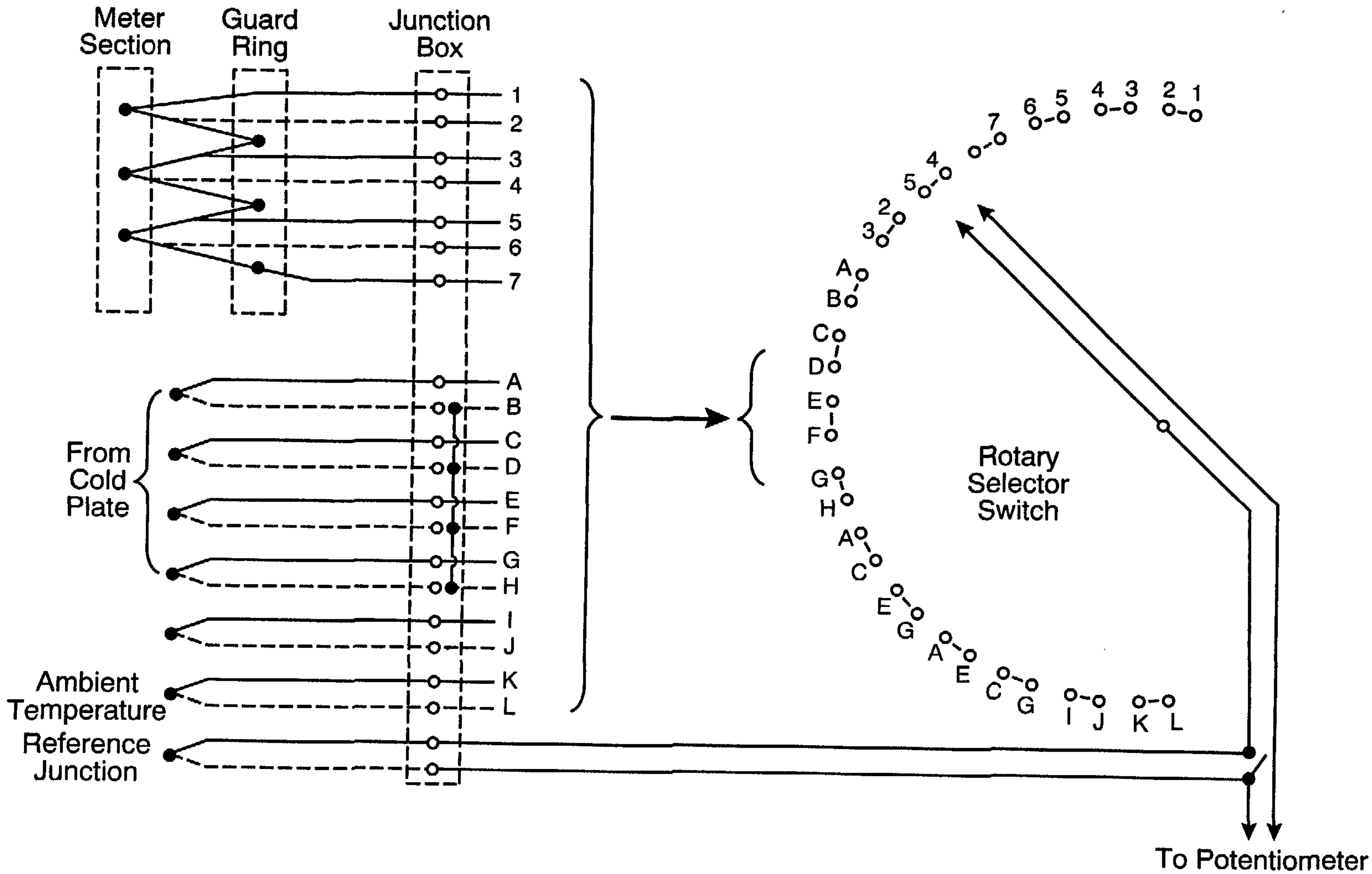
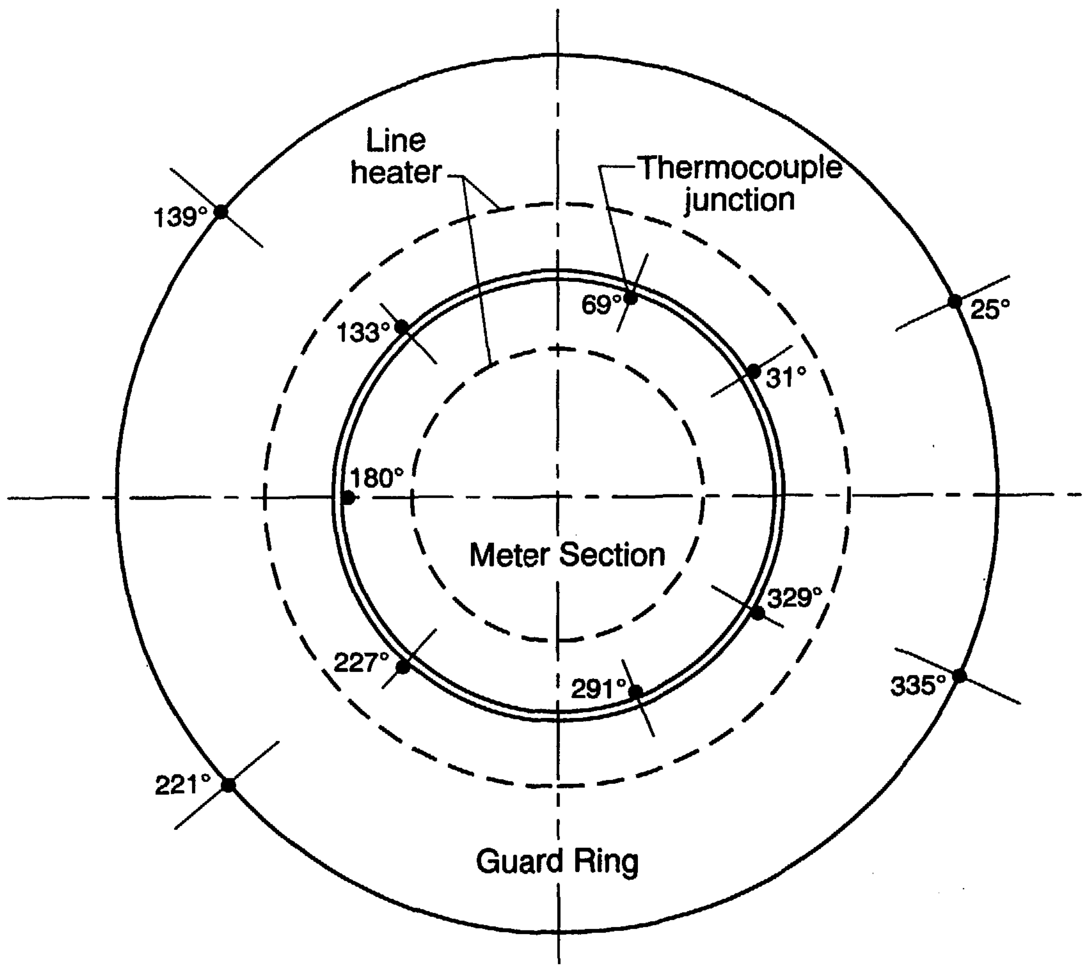

0.13 mm
(typical)
Lead
wire
Ribbon
heater
Heat sink
compound
Line Heater Installation
(Taper Fit)
Set screw
Pin
Gap
Support Mechanism
Swaged
heater
a
Guard ring
Meter section
Guard ring

Figure 4



Meter Section
Guard Ring
Junction Box
1
2
3
4
5
6
7
A
B
C
D
E
F
G
H
I
J
K
L
From Cold Plate
Ambient Temperature
Reference Junction
Rotary Selector Switch
To Potentiometer

Figure 5



Line
heater
Thermocouple
junction
139°
133°
69°
25°
31°
180°
Meter Section
329°
227°
291°
335°
221°
Guard Ring

Figure 6

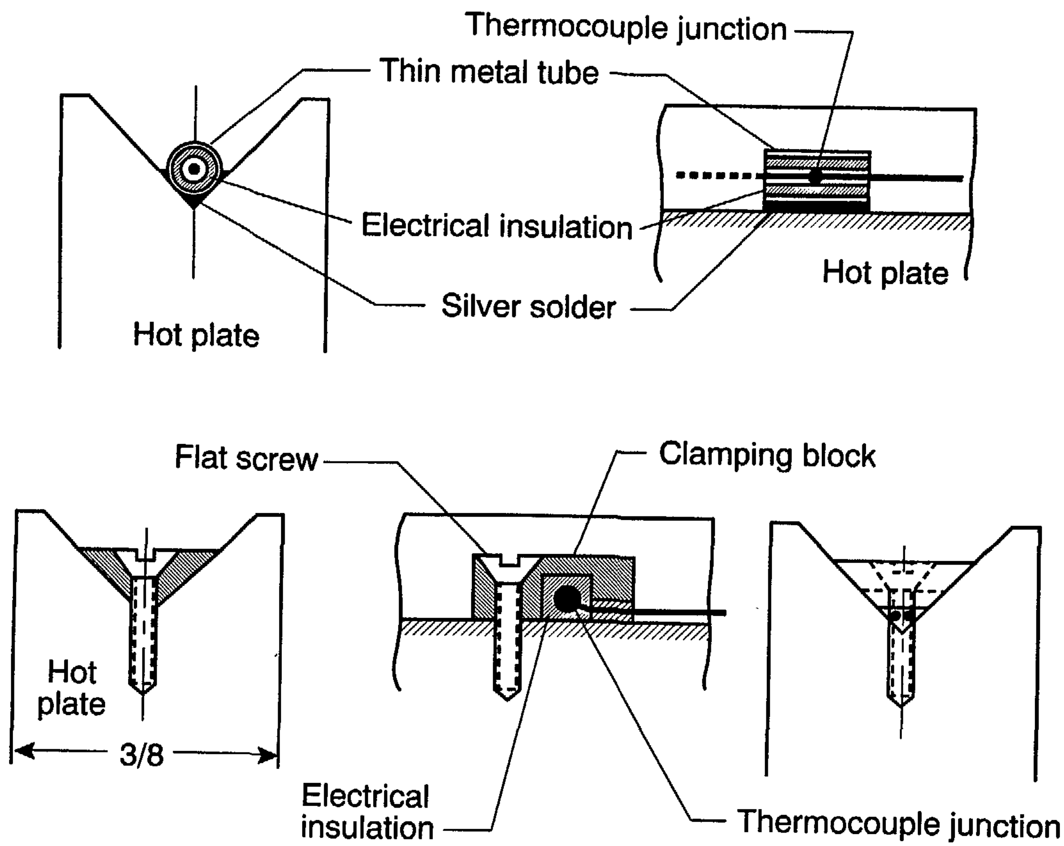
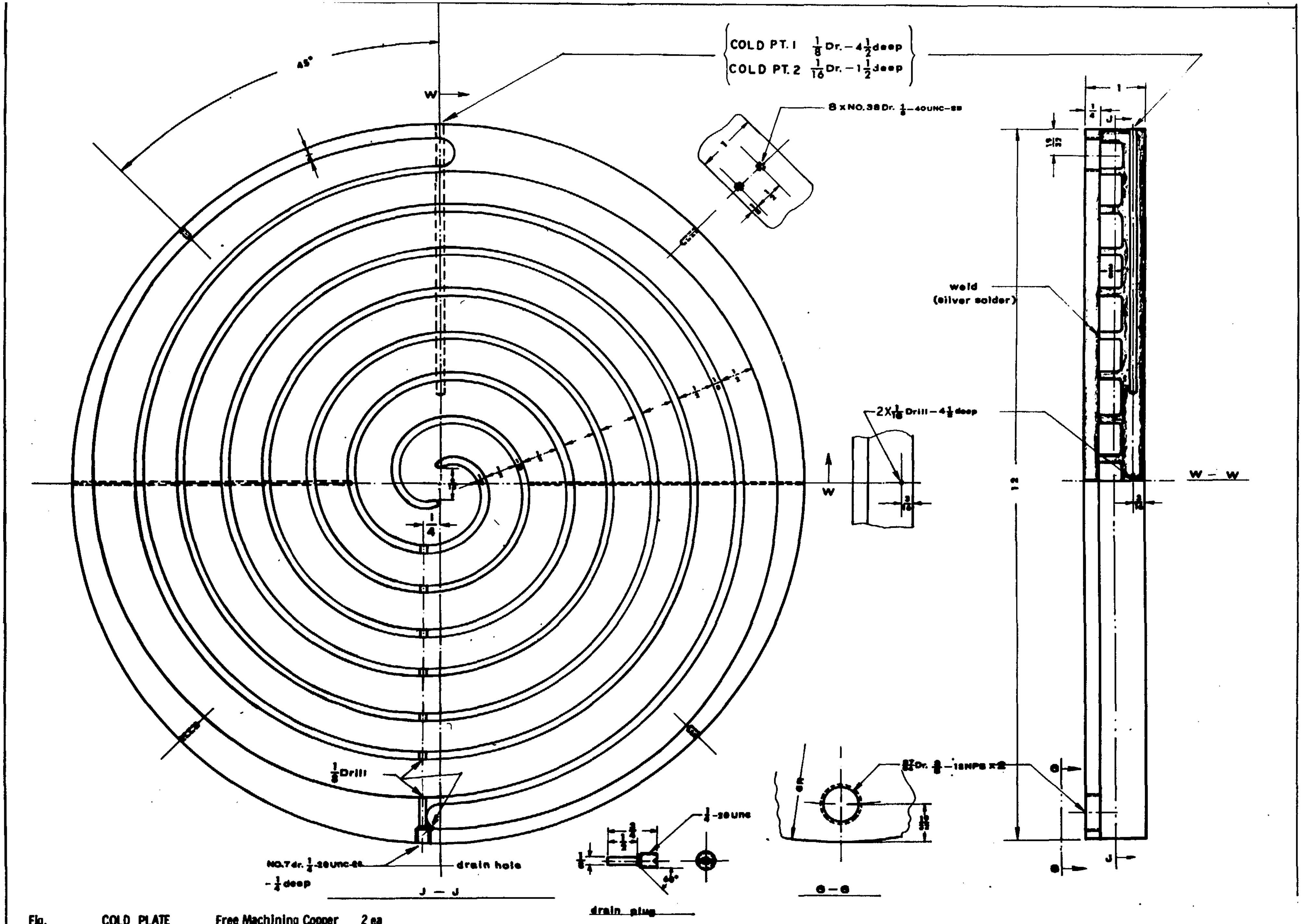
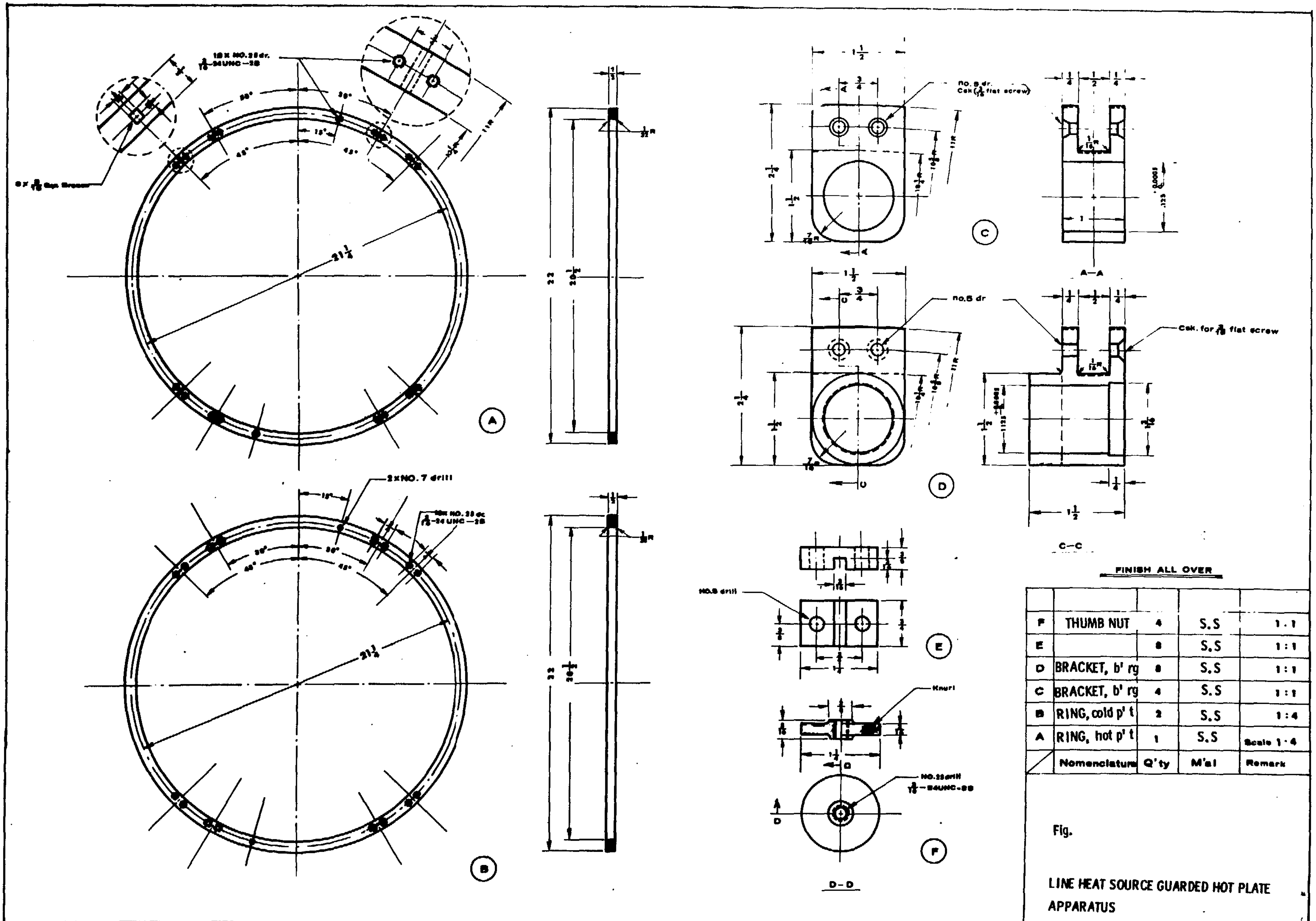

Thermocouple junction
Thin metal tube
Electrical insulation
Silver solder
Hot plate
Hot plate
Flat screw
Clamping block
Hot plate
3/8
Electrical insulation
Thermocouple junction

Figure 7



COLD PT. 1 $\frac{1}{8}$ Dr. – $4\frac{1}{2}$ deep
COLD PT. 2 $\frac{1}{16}$ Dr. – $1\frac{1}{2}$ deep
45°
W
8 x NO. 38 Dr. $\frac{1}{8}$–40UNC–2B
weld
(silver solder)
2X$\frac{1}{16}$ Drill – $4\frac{1}{2}$ deep
W – W
$\frac{1}{4}$
$\frac{1}{8}$ Drill
$\frac{1}{4}$–20UNC
NO.7 dr. $\frac{1}{4}$–20UNC–2B
– $\frac{1}{4}$ deep
drain hole
J – J
drain plug
G – G
FINISH ALL OVER Scale 1:1
Surface flatness
Fig.
COLD PLATE
Free Machining Copper
2 ea

Figure 8



	Nomenclature	Q'ty	M'al	Remark
F	THUMB NUT	4	S.S	1:1
E		8	S.S	1:1
D	BRACKET, b' rg	8	S.S	1:1
C	BRACKET, b' rg	4	S.S	1:1
B	RING, cold p' t	2	S.S	1:4
A	RING, hot p' t	1	S.S	Scale 1:4

Figure 9

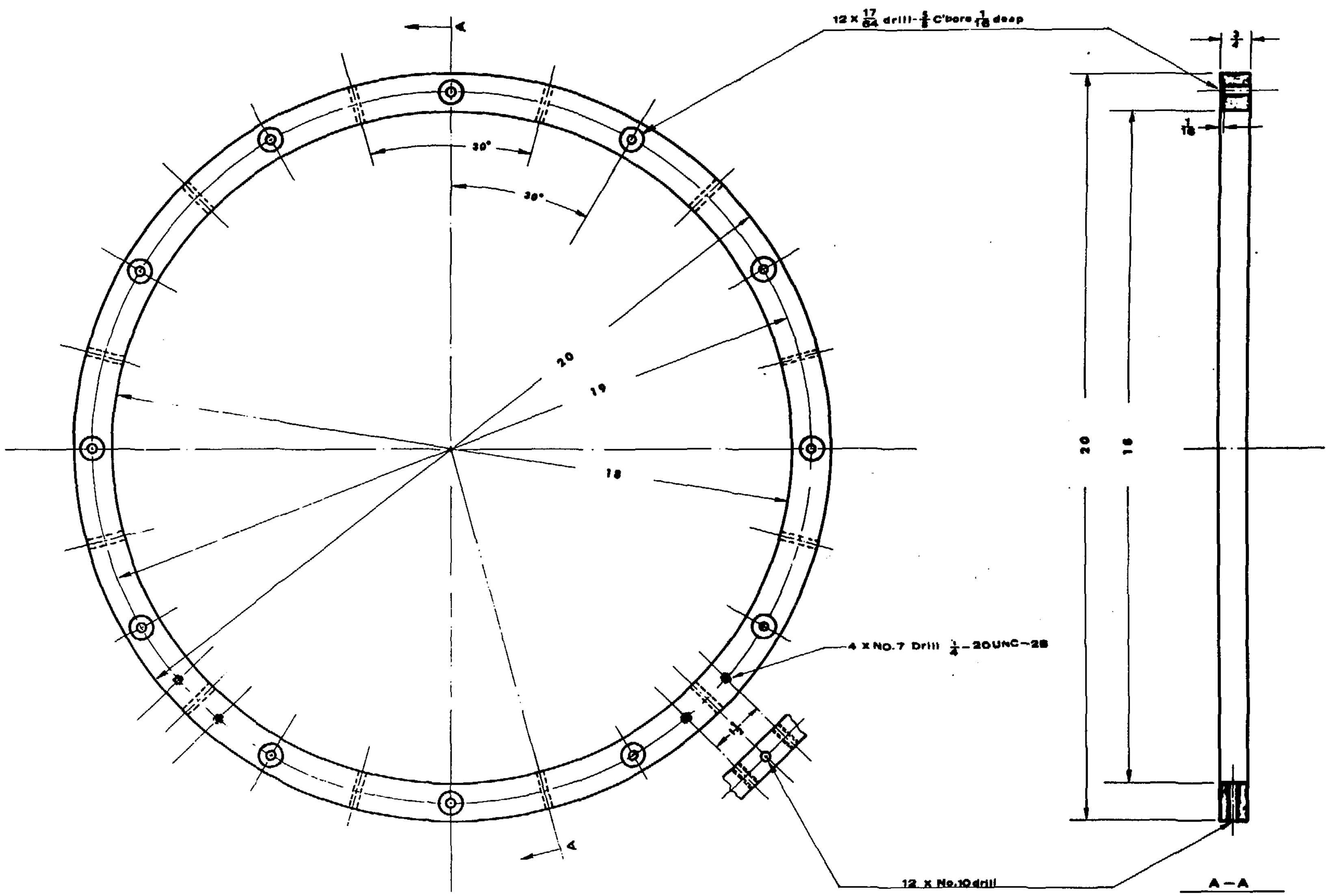
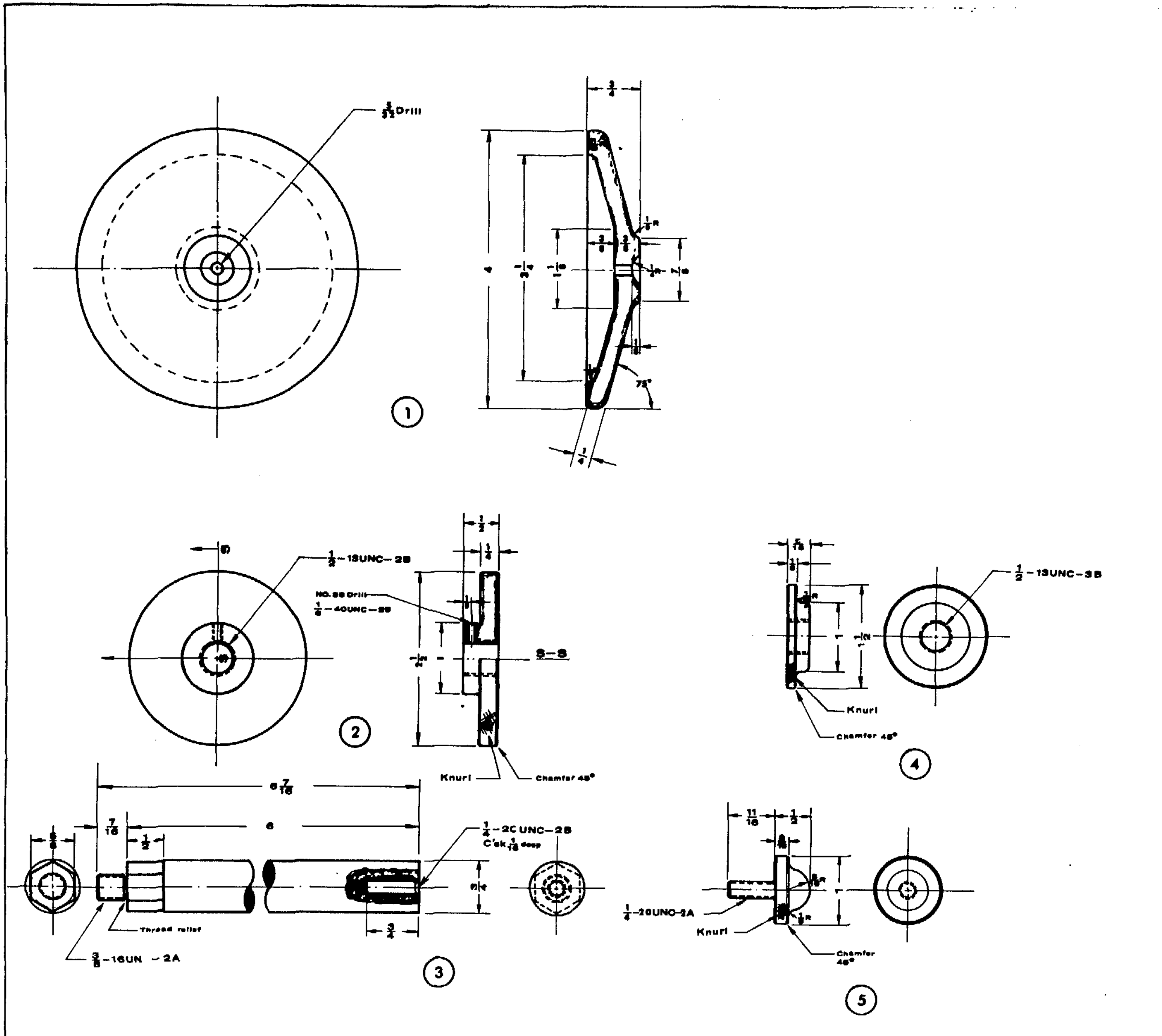


FIG. SIDE RING
MATERIAL: STAINLESS STEEL
Q'ty : 2 EA

FINISH ALL OVER SCALE

Figure 10



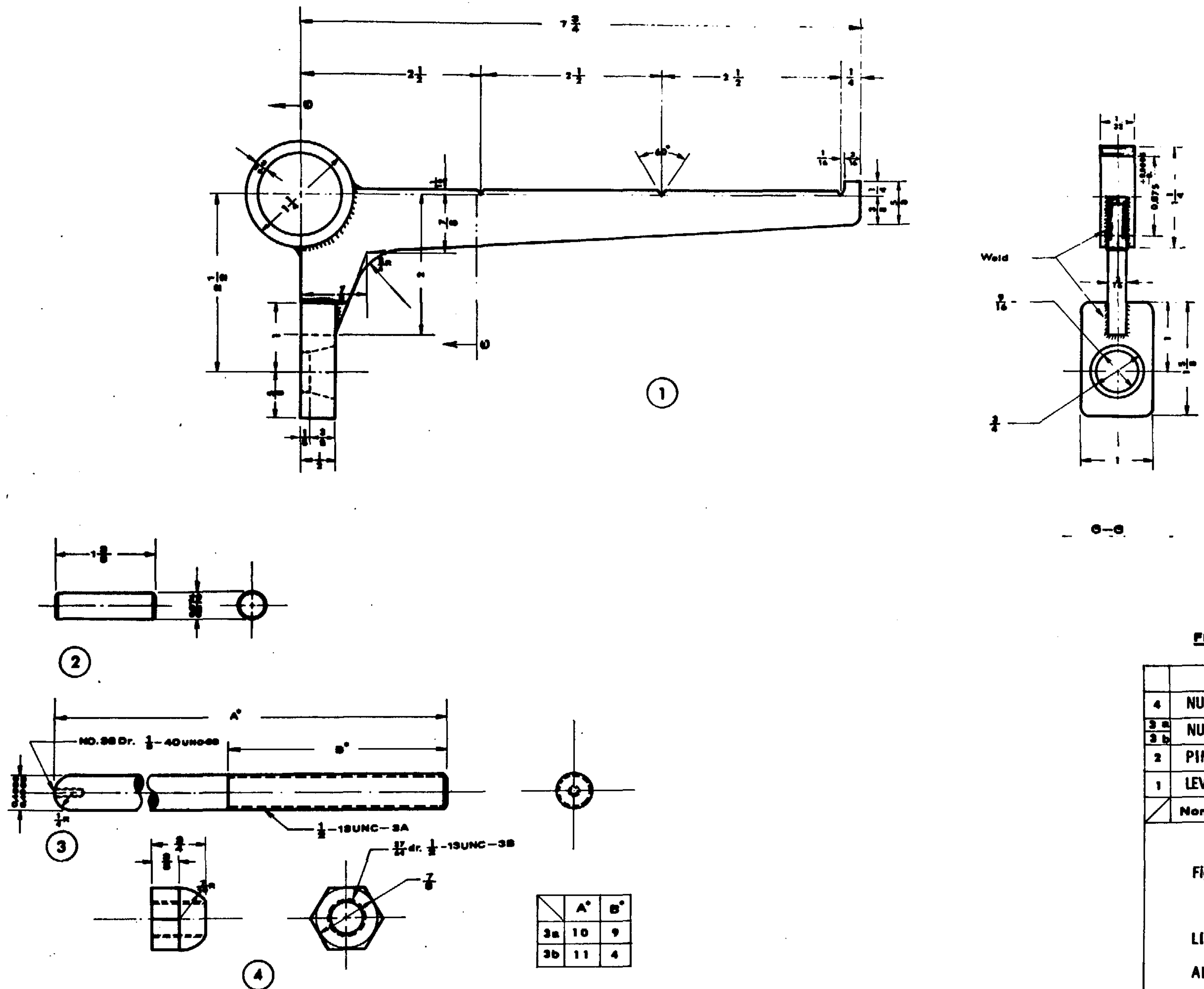
FINISH ALL OVER Scale 1:1

5	FEET	4	S.S	
4	STOPPER	2	S.S	
3	LEG	4	S.S	
2	KNOB, thumb	1	S.S	
1	CUP, thrust	2	S.S	
	Nomenclature	Q'ty	M'al	Remark

Fig.

LINE HEAT SOURCE GUARDED HOT PLATE APPARATUS

Figure 11



	A°	B°
3a	10	9
3b	11	4

FINISH ALL OVER Scale

4	NUT, lock	1	S.S	
3a / 3b	NUT, thrust	1 / 1	S.S	
2	PIN	1	S.S	
1	LEVER	1	S.S	
	Nomenclature	Q'ty	M'al	Remark

Fig.

LINE HEAT SOURCE GUARDED HOT PLATE APPARATUS

Figure 12

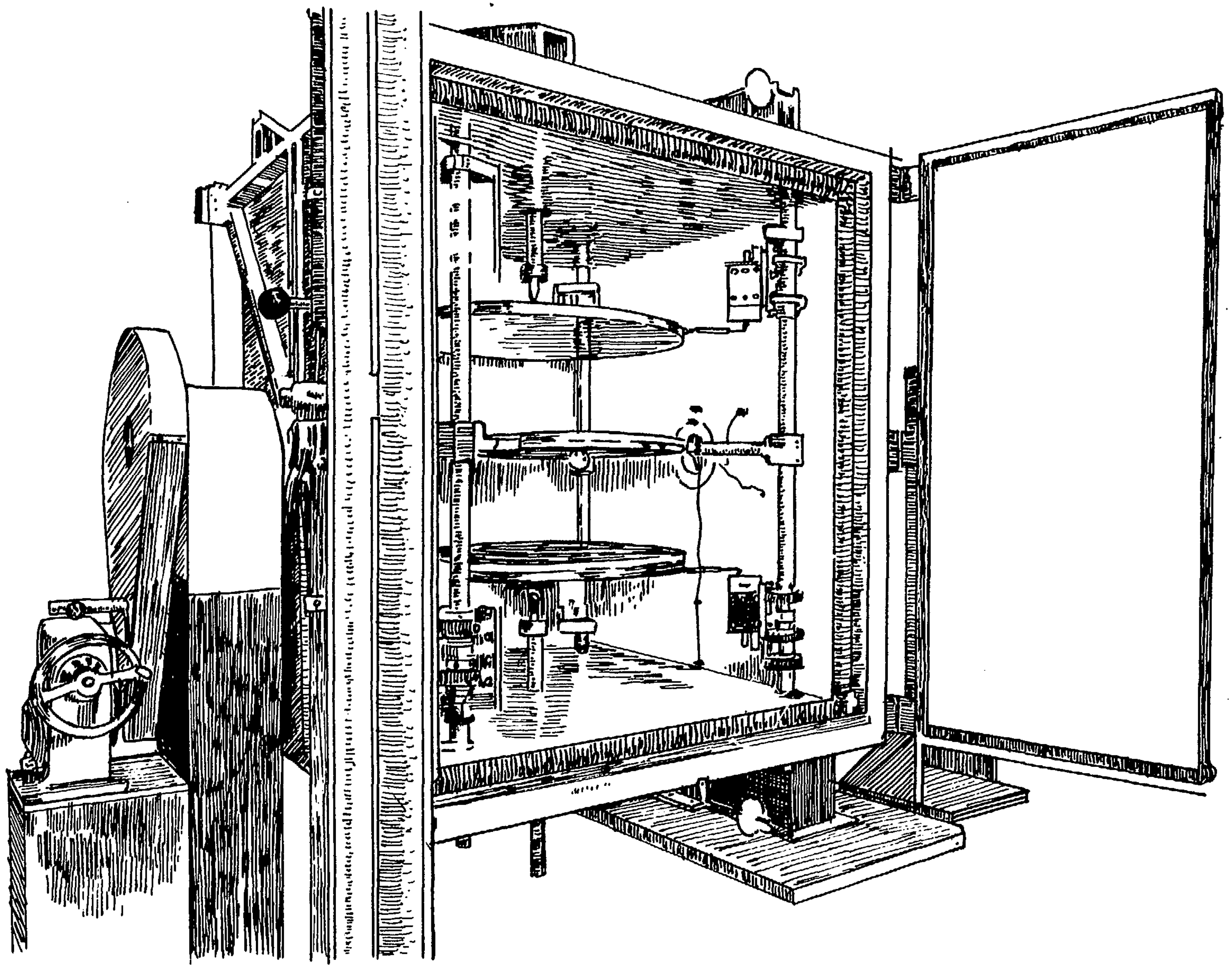
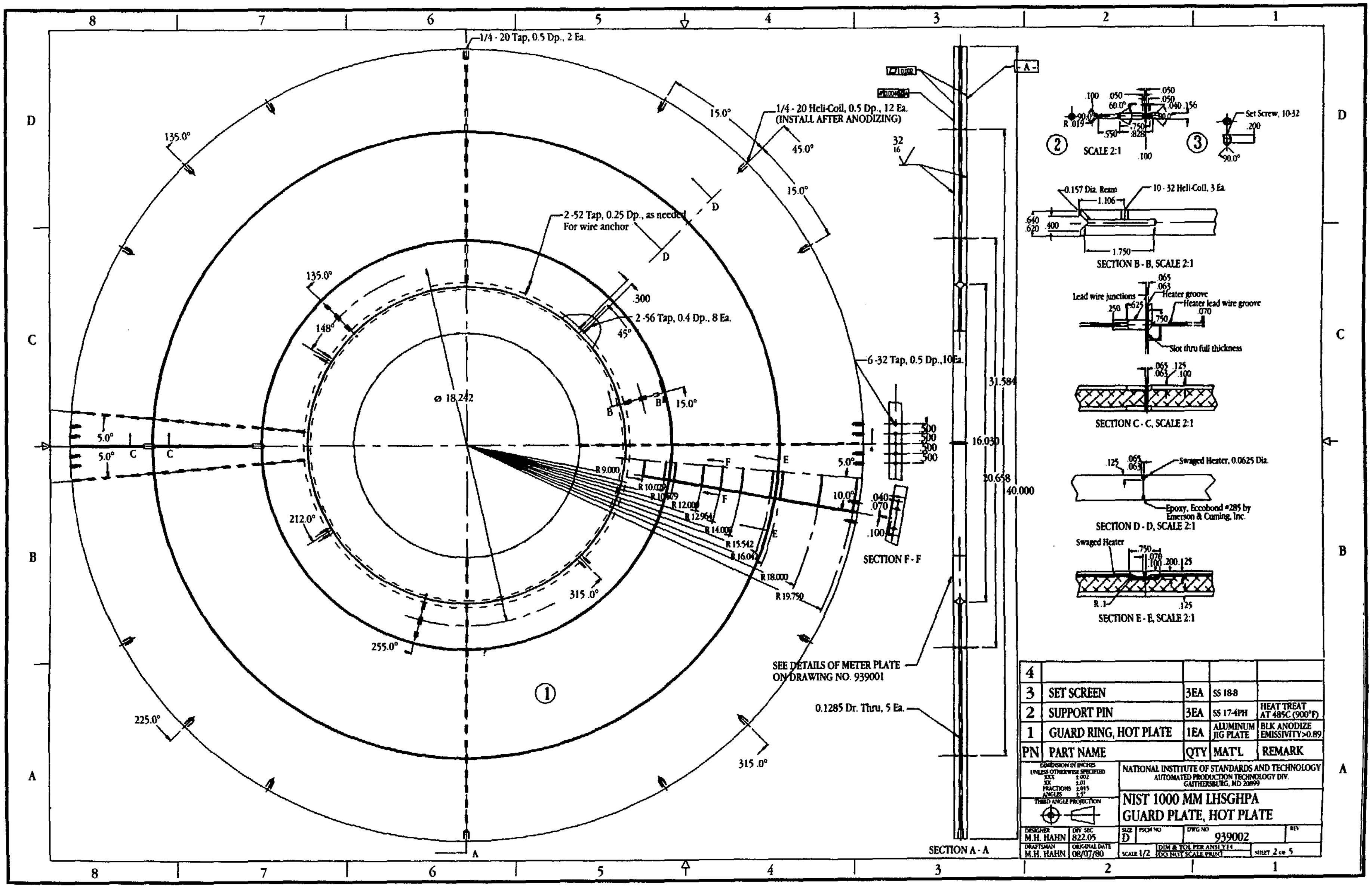


Figure 13



1/4 - 20 Tap, 0.5 Dp., 2 Ea.
1/4 - 20 Heli-Coil, 0.5 Dp., 12 Ea.
(INSTALL AFTER ANODIZING)
2 -52 Tap, 0.25 Dp., as needed
For wire anchor
2 -56 Tap, 0.4 Dp., 8 Ea.
6 -32 Tap, 0.5 Dp., 10 Ea.
ø 18.242
SECTION F - F
SEE DETAILS OF METER PLATE ON DRAWING NO. 939001
0.1285 Dr. Thru, 5 Ea.
SECTION A - A
SCALE 2:1
Set Screw, 10-32
0.157 Dia. Ream
10 - 32 Heli-Coil, 3 Ea.
SECTION B - B, SCALE 2:1
Lead wire junctions
Heater groove
Heater lead wire groove
Slot thru full thickness
SECTION C - C, SCALE 2:1
Swaged Heater, 0.0625 Dia.
Epoxy, Eccobond #285 by Emerson & Cuming, Inc.
SECTION D - D, SCALE 2:1
Swaged Heater
SECTION E - E, SCALE 2:1
4
3 SET SCREEN 3EA SS 18-8
2 SUPPORT PIN 3EA SS 17-4PH HEAT TREAT AT 485C (900°F)
1 GUARD RING, HOT PLATE 1EA ALUMINUM JIG PLATE BLK ANODIZE EMISSIVITY>0.89
PN PART NAME QTY MAT'L REMARK
NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
AUTOMATED PRODUCTION TECHNOLOGY DIV.
GAITHERSBURG, MD 20899
NIST 1000 MM LHSGHPA
GUARD PLATE, HOT PLATE
THIRD ANGLE PROJECTION
DESIGNER M.H. HAHN
DRAFTSMAN M.H. HAHN
DIV SEC 822.05
ORIGINAL DATE 08/07/80
SIZE D
DWG NO 939002
SCALE 1/2
DO NOT SCALE PRINT

Figure 14

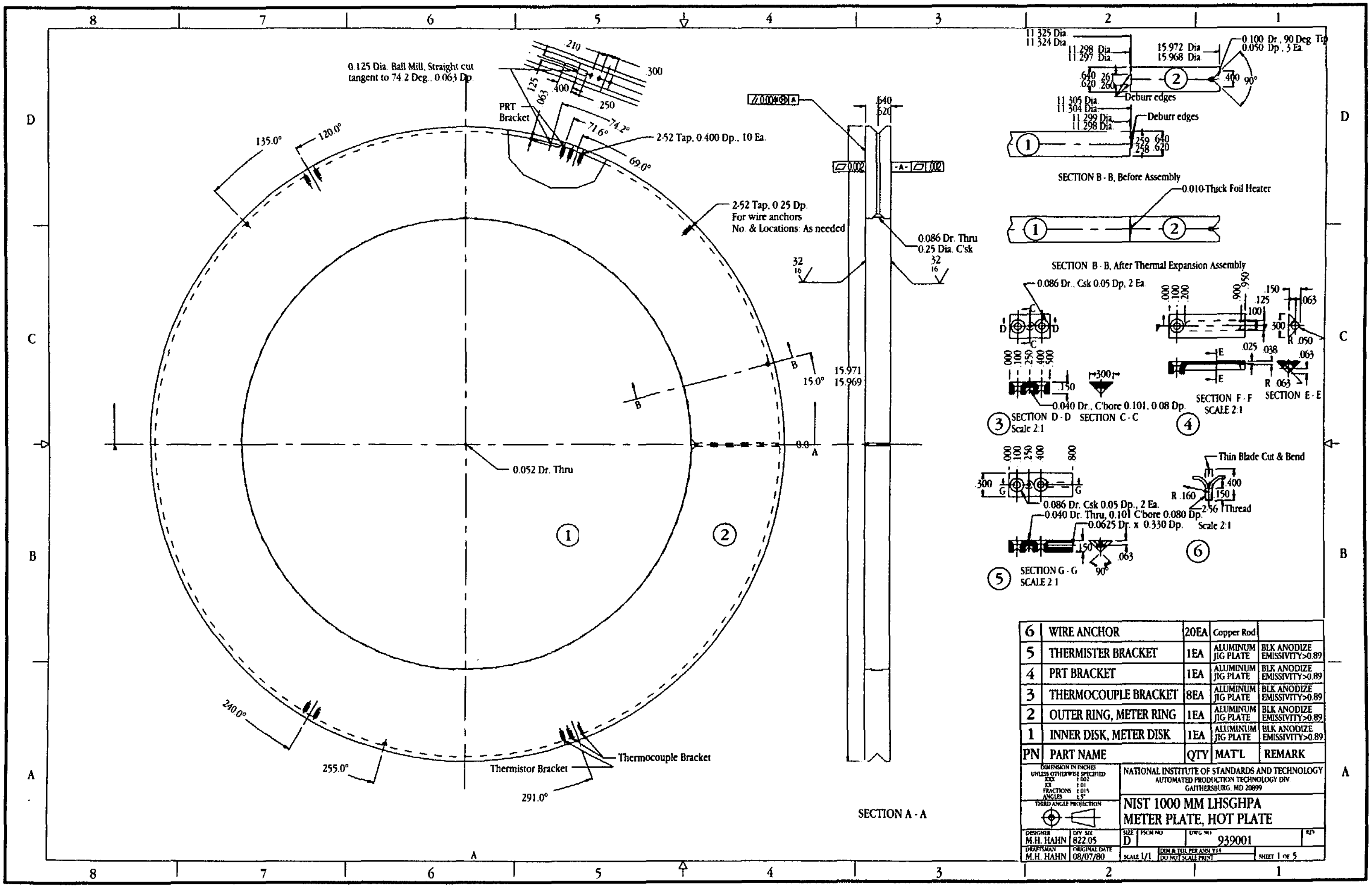

0.125 Dia. Ball Mill, Straight cut tangent to 74.2 Deg., 0.063 Dp.
PRT Bracket
2-52 Tap, 0.400 Dp., 10 Ea.
2-52 Tap, 0.25 Dp. For wire anchors No. & Locations: As needed
0.052 Dr. Thru
Thermistor Bracket
Thermocouple Bracket
0.086 Dr. Thru
0.25 Dia. C'sk
SECTION A - A
Deburr edges
SECTION B - B, Before Assembly
0.010-Thick Foil Heater
SECTION B - B, After Thermal Expansion Assembly
0.086 Dr., Csk 0.05 Dp, 2 Ea.
0.040 Dr., C'bore 0.101, 0.08 Dp.
SECTION D - D
SECTION C - C
Scale 2:1
SECTION F - F
SCALE 2:1
SECTION E - E
0.086 Dr. Csk 0.05 Dp., 2 Ea.
0.040 Dr. Thru, 0.101 C'bore 0.080 Dp.
0.0625 Dr. x 0.330 Dp.
SECTION G - G
SCALE 2:1
Thin Blade Cut & Bend
2-56 Thread
Scale 2:1
6 WIRE ANCHOR 20EA Copper Rod
5 THERMISTER BRACKET 1EA ALUMINUM JIG PLATE BLK ANODIZE EMISSIVITY>0.89
4 PRT BRACKET 1EA ALUMINUM JIG PLATE BLK ANODIZE EMISSIVITY>0.89
3 THERMOCOUPLE BRACKET 8EA ALUMINUM JIG PLATE BLK ANODIZE EMISSIVITY>0.89
2 OUTER RING, METER RING 1EA ALUMINUM JIG PLATE BLK ANODIZE EMISSIVITY>0.89
1 INNER DISK, METER DISK 1EA ALUMINUM JIG PLATE BLK ANODIZE EMISSIVITY>0.89
PN PART NAME QTY MAT'L REMARK
NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
AUTOMATED PRODUCTION TECHNOLOGY DIV
GAITHERSBURG, MD 20899
NIST 1000 MM LHSGHPA
METER PLATE, HOT PLATE
DESIGNER M.H. HAHN
DRAFTSMAN M.H. HAHN
DIV SEC 822.05
ORIGINAL DATE 08/07/80
SIZE D
DWG NO 939001
SCALE 1/1
SHEET 1 OF 5

Figure 15

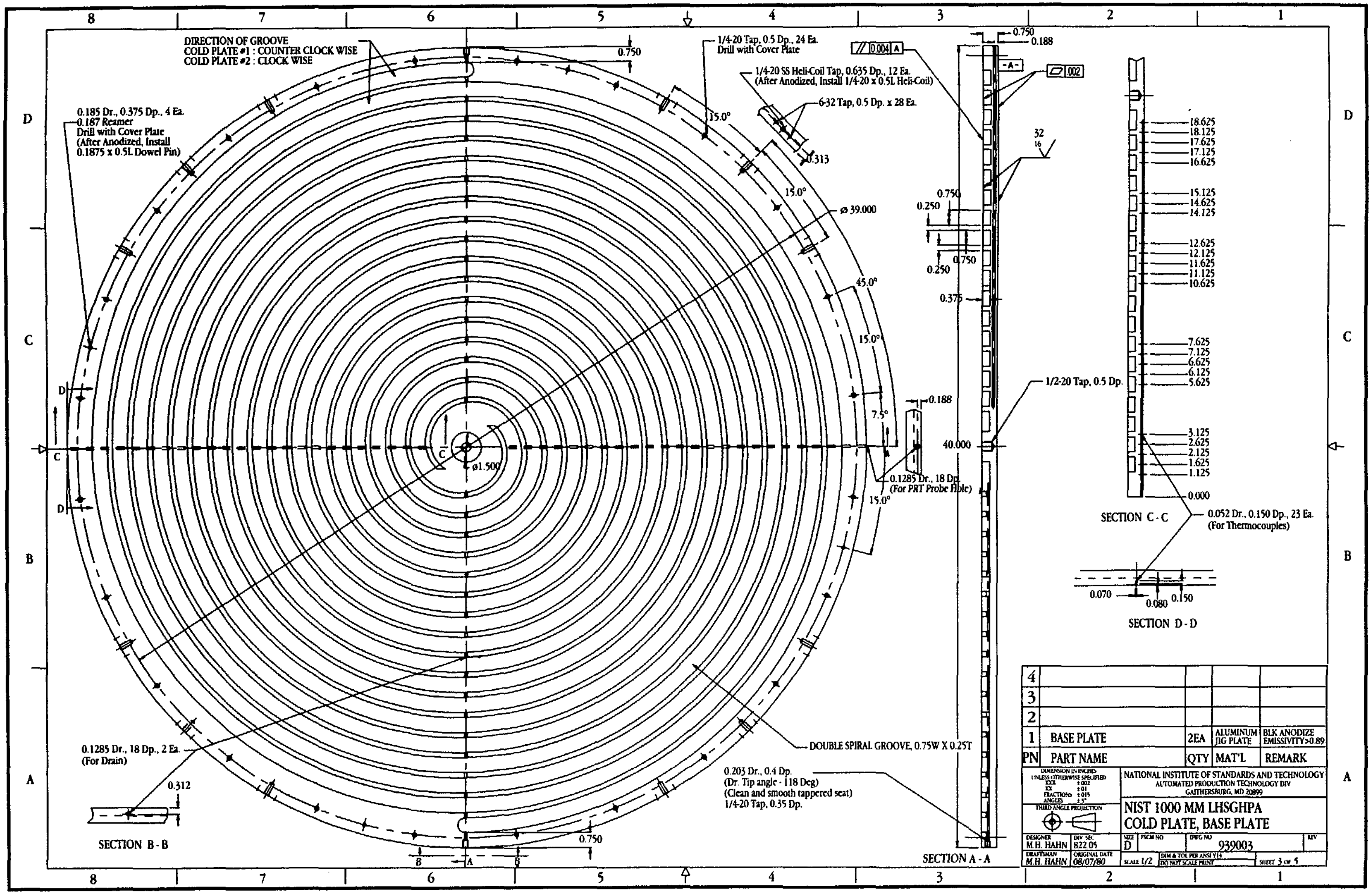
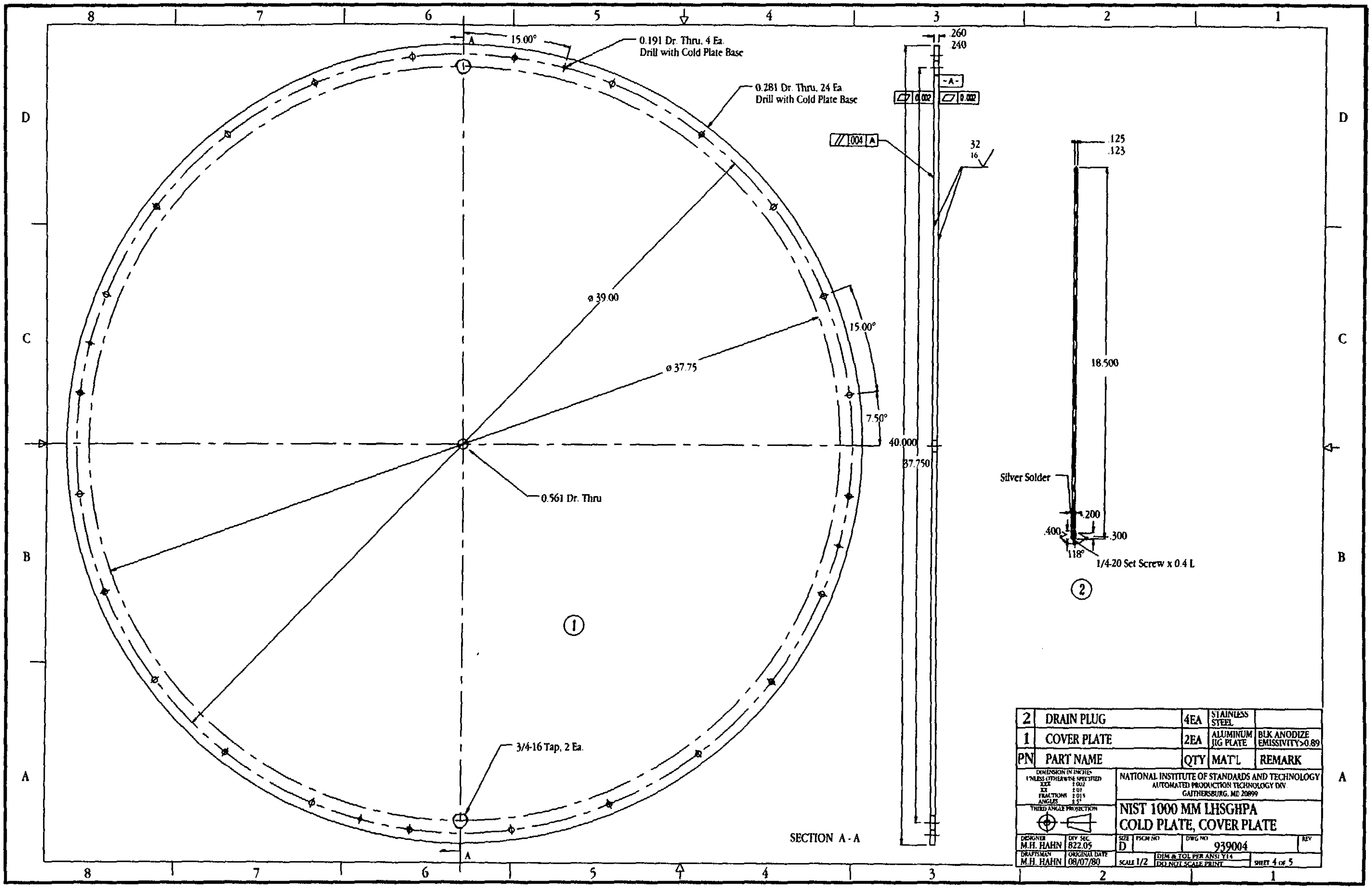

DIRECTION OF GROOVE
COLD PLATE #1 : COUNTER CLOCK WISE
COLD PLATE #2 : CLOCK WISE
0.185 Dr., 0.375 Dp., 4 Ea.
0.187 Reamer
Drill with Cover Plate
(After Anodized, Install
0.1875 x 0.5L Dowel Pin)
1/4-20 Tap, 0.5 Dp., 24 Ea.
Drill with Cover Plate
1/4-20 SS Heli-Coil Tap, 0.635 Dp., 12 Ea.
(After Anodized, Install 1/4-20 x 0.5L Heli-Coil)
6-32 Tap, 0.5 Dp. x 28 Ea.
0.313
ø 39.000
45.0°
15.0°
7.5°
0.188
0.1285 Dr., 18 Dp.
(For PRT Probe Hole)
ø1.500
0.750
0.1285 Dr., 18 Dp., 2 Ea.
(For Drain)
0.312
SECTION B - B
DOUBLE SPIRAL GROOVE, 0.75W X 0.25T
0.203 Dr., 0.4 Dp.
(Dr. Tip angle - 118 Deg)
(Clean and smooth tappered seat)
1/4-20 Tap, 0.35 Dp.
SECTION A - A
40.000
0.375
0.250
1/2-20 Tap, 0.5 Dp.
SECTION C - C
0.000
1.125
1.625
2.125
2.625
3.125
5.625
6.125
6.625
7.125
7.625
10.625
11.125
11.625
12.125
12.625
14.125
14.625
15.125
16.625
17.125
17.625
18.125
18.625
0.052 Dr., 0.150 Dp., 23 Ea.
(For Thermocouples)
0.070
0.080
0.150
SECTION D - D
PN | PART NAME | QTY | MAT'L | REMARK
1 | BASE PLATE | 2EA | ALUMINUM JIG PLATE | BLK ANODIZE EMISSIVITY>0.89
NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
AUTOMATED PRODUCTION TECHNOLOGY DIV
GAITHERSBURG, MD 20899
NIST 1000 MM LHSGHPA
COLD PLATE, BASE PLATE
DESIGNER M.H. HAHN
DIV SEC 822.05
DRAFTSMAN M.H. HAHN
ORIGINAL DATE 08/07/80
SIZE D
DWG NO 939003
SCALE 1/2
SHEET 3 OF 5

Figure 16



0.191 Dr. Thru. 4 Ea.
Drill with Cold Plate Base
0.281 Dr. Thru. 24 Ea.
Drill with Cold Plate Base
15.00°
15.00°
7.50°
ø 39.00
ø 37.75
0.561 Dr. Thru
3/4-16 Tap, 2 Ea.
.260
.240
-A-
0.002
0.002
.004 A
32
16
40.000
37.750
SECTION A - A
.125
.123
18.500
Silver Solder
.200
.400
.300
118°
1/4-20 Set Screw x 0.4 L
2 DRAIN PLUG 4EA STAINLESS STEEL
1 COVER PLATE 2EA ALUMINUM JIG PLATE BLK ANODIZE EMISSIVITY>0.89
PN PART NAME QTY MAT'L REMARK
NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
AUTOMATED PRODUCTION TECHNOLOGY DIV
GAITHERSBURG, MD 20899
NIST 1000 MM LHSGHPA
COLD PLATE, COVER PLATE
DESIGNER M.H. HAHN
DIV SEC 822.05
DRAFTSMAN M.H. HAHN
ORIGINAL DATE 08/07/80
SIZE D
DWG NO 939004
SCALE 1/2
SHEET 4 OF 5

Figure 17

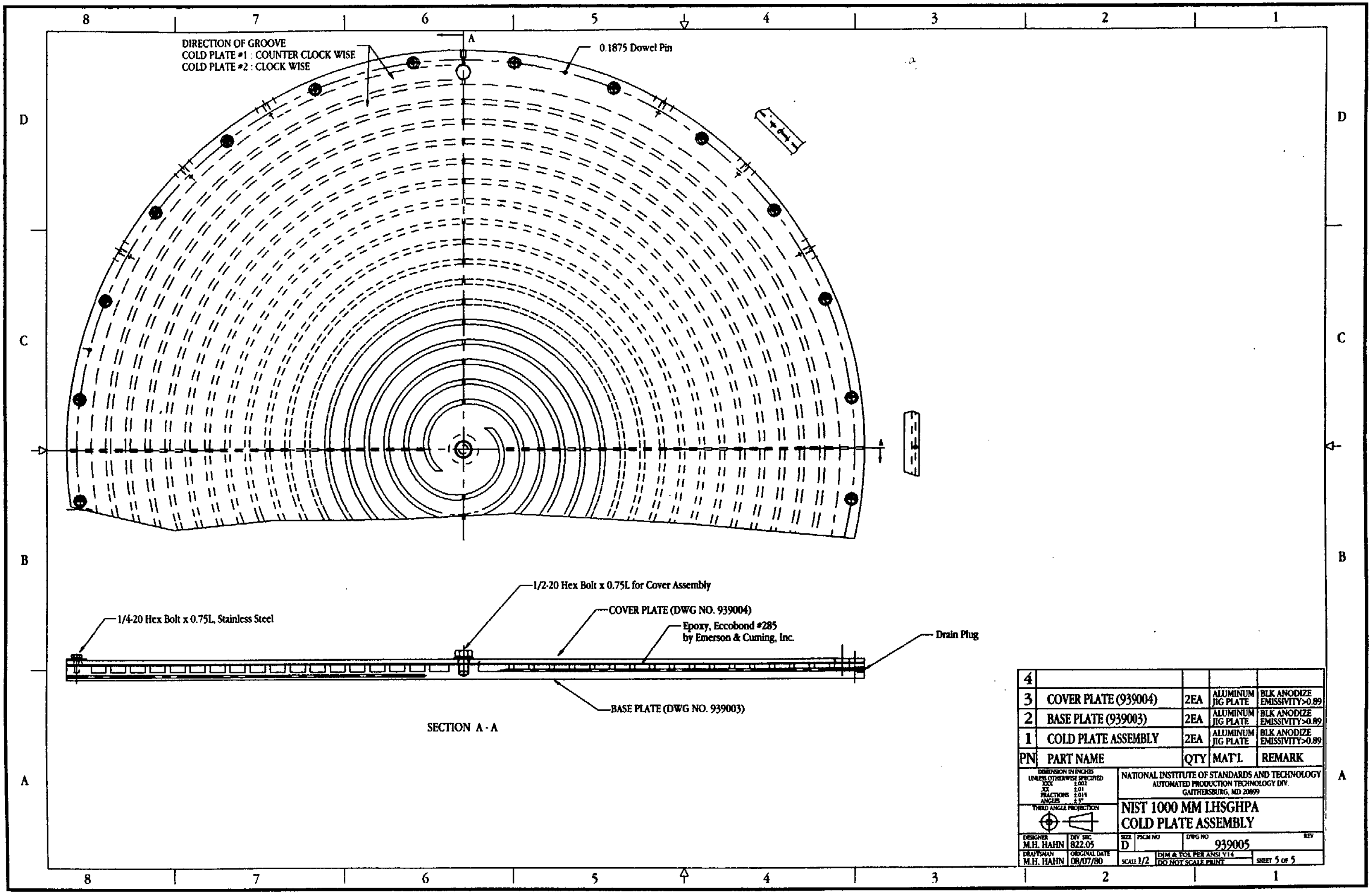

DIRECTION OF GROOVE
COLD PLATE #1 : COUNTER CLOCK WISE
COLD PLATE #2 : CLOCK WISE
0.1875 Dowel Pin
A
1/4-20 Hex Bolt x 0.75L, Stainless Steel
1/2-20 Hex Bolt x 0.75L for Cover Assembly
COVER PLATE (DWG NO. 939004)
Epoxy, Eccobond #285
by Emerson & Cuming, Inc.
Drain Plug
BASE PLATE (DWG NO. 939003)
SECTION A - A
4
3 COVER PLATE (939004) 2EA ALUMINUM JIG PLATE BLK ANODIZE EMISSIVITY>0.89
2 BASE PLATE (939003) 2EA ALUMINUM JIG PLATE BLK ANODIZE EMISSIVITY>0.89
1 COLD PLATE ASSEMBLY 2EA ALUMINUM JIG PLATE BLK ANODIZE EMISSIVITY>0.89
PN PART NAME QTY MAT'L REMARK
NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
AUTOMATED PRODUCTION TECHNOLOGY DIV.
GAITHERSBURG, MD 20899
NIST 1000 MM LHSGHPA
COLD PLATE ASSEMBLY
DESIGNER M.H. HAHN
DIV SEC 822.05
DRAFTSMAN M.H. HAHN
ORIGINAL DATE 08/07/90
SIZE D
DWG NO 939005
SCALE 1/2
DO NOT SCALE PRINT
SHEET 5 OF 5

Figure 18

Figure A1